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A PERSPECTIVE ON DEVELOPMENT FLIGHT INSTRUMENTATION AND FLIGHT TEST ANALYSIS PLANS FOR ARES I-X

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ABSTRACT

NASA's Constellation Program will take a significant step toward completion of the Ares I crew launch vehicle with the flight test of Ares I-X and completion of the Ares I-X post-flight evaluation. The Ares I-X flight test vehicle is an ascent development flight test that will acquire flight data early enough to impact the design and development of the Ares I. As the primary customer for flight data from the Ares I-X mission, Ares I has been the major driver in the definition of the Development Flight Instrumentation (DFI). This paper focuses on the DFI development process and the plans for post-flight evaluation of the resulting data to impact the Ares I design.

Efforts for determining the DFI for Ares I-X began in the fall of 2005, and significant effort to refine and implement the Ares I-X DFI has been expended since that time. This paper will present a perspective in the development and implementation of the DFI. Emphasis will be placed on the process by which the list was established and changes were made to that list due to imposed constraints. The paper will also discuss the plans for the analysis of the DFI data following the flight and a summary of flight evaluation tasks to be performed in support of tools and models validation for design and development.

INTRODUCTION

The National Aeronautics and Space Administration (NASA) has been carefully planning a series of development and validation test flights to ensure that the vehicles included as part of the Constellation Program are appropriately designed and ready for human space flight. The first flight test of relevance to the Ares I project is the 2009 launch of the Ares I-X flight test vehicle, an unscrewed, ascent development flight test that will acquire flight data early enough to inform and impact the design and development of the Ares I. The primary stakeholder organizations within Constellation are the Ares Projects Office (APO) at Marshall Space Flight Center in Alabama, the Orion Project Office at Johnson Space Center in Texas, and the Ground Operations and Ground Systems Offices at Kennedy Space Center (KSC) in Florida. The Ares I-X is being developed in accordance with the requirements set forth in the Ares I-X System Requirements Document,[1] which emanate from the Constellation Program Ares I-X Flight Test Plan.[2] The Ares I-X characteristics and performance are sufficiently similar to the Ares I to meet the test flight objectives and provide significant data that will validate models for and impact the Ares I design.[3]

Ares I-X Configuration Overview

The Ares I-X Mission Management Office (MMO) is responsible for the development and execution of the Ares I-X flight test. Figure 1 presents a top-level overview of the Ares I-X configuration.[4] Five major hardware elements comprise the Ares I-X. These include the First Stage (FS), the mass and outer mold line (OML) simulators of the Upper Stage and Crew Module/Launch Abort System (CM/LAS), the Roll Control System (RoCS), and the Avionics (parts of which are distributed throughout the vehicle). A team led by the Langley Research Center in Virginia is responsible for executing the Systems Engineering and Integration (SE&I) function for Ares I-X.

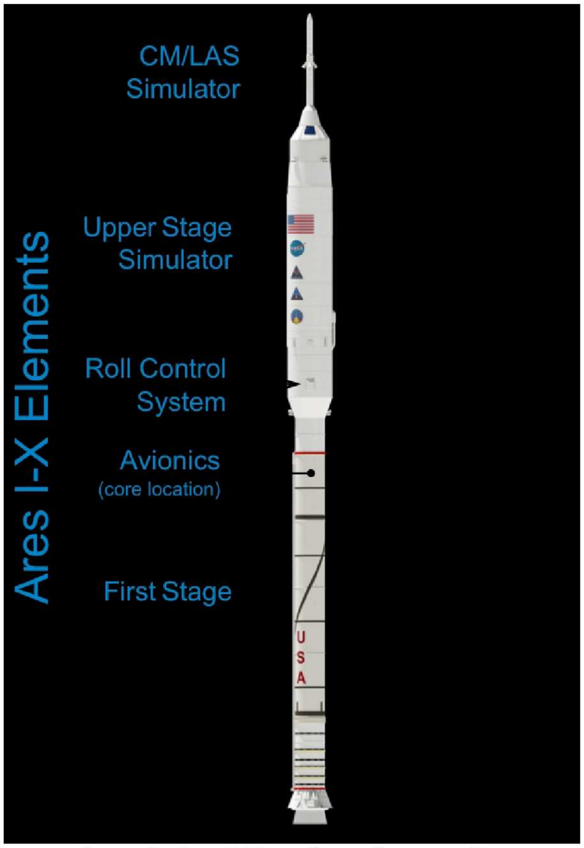

Figure 1. Ares I-X configuration overview.

The FS is representative of the Ares I five-segment booster first stage OML. It is comprised of a four-segment Space Shuttle Reusable Solid Rocket Motor (RSRM), an empty (no propellant) fifth motor segment, the forward skirt extension, the forward skirt (containing the first stage recovery systems), and the frustum to carry vehicle loads to the interstage. Since a four segment motor is used, the empty fifth segment is included for vehicle similarity and to demonstrate descent and recovery of a spent Ares I FS per flight test objectives.

The Upper Stage Simulator (USS) is comprised of an interstage beginning at the FS interface, a physical simulator of the Ares I Upper Stage, and simulators for the spacecraft adapter and service module. These last two subsystems are part of the Orion configuration, but included in USS for this development. The CM/LAS simulator is a physical representation of an earlier design of the Orion elements of the same name.

The RoCS modules are located on the interstage simulator of the USS and provide Ares I-X roll control during ascent. Each module consists of two pairs of thrusters mounted perpendicular to the vehicle x-axis on either side of the interstage. The RoCS for Ares I-X primarily consists of hardware harvested from the Peacekeeper ballistic missile fourth stage axial thruster system and provides a thrust capability from each thruster that is higher than that which is currently being designed for Ares I. The RoCS will be controlled via the Ares I-X Avionics subsystem.

The Avionics subsystem provides a number of important capabilities for Ares I-X, including flight vehicle guidance, navigation, and control (consisting of sensing vehicle dynamics and interfaces to the RoCS and ascent thrust vector control system); sequencing of mission events from launch through recovery; data acquisition of Development Flight Instrumentation (DFI) and Operational Flight Instrumentation (OFI); video imaging as part of the DFI system; telemetry and recording of OFI and DFI data; and power sourcing, management, and distribution.

Ares I-X Flight Test Scenario

Ares I-X is a suborbital test flight planned for the Fall of 2009 and does not fly with a human crew. Like Ares I, Ares I-X will be launched from KSC Launch Complex 39B. As shown in Figure 2, the FS will provide primary propulsion from liftoff to stage separation. The FS will fire for approximately two minutes prior to separation. After separation from the rest of Ares I-X (physical separation takes place at the bottom of the frustum), the FS will descend and splashdown in the Atlantic Ocean to be recovered. Meanwhile, the simulator comprised of the CM/LAS, the USS, the interstage, and the FS frustum continues in an uncontrolled, ballistic trajectory until impact in the Atlantic Ocean farther downrange.

Figure 2. Ares I-X flight scenario.

DEVELOPMENT FLIGHT INSTRUMENTATION

History of DFI Measurement List Creation

In November 2005, the first formal discussions for Ares I-X instrumentation took place. The results of this meeting were a first attempt at creating an instrumentation sensor list and a discussion of Ares I-X flight test objectives (which had not been fully approved at that time). This very preliminary list consisted of about 200 measurements on the RSRM (e.g., pressures, temperatures, strains, and actuator positions); about 1,000 measurements to characterize the induced loads on the rest of Ares I-X; about 100 air-data and flight control system measurements; 1,000 OFI parameters; and two high-bandwidth, on-board video cameras.

A few months later, most (but not all) of the technical disciplines supporting the Ares Projects Office performed a more rigorous and systematic layout of sensors for Ares I-X to produce a baseline set of measurements. That set is shown in Table 1. This list (with 30% growth margin) consisted of about 2,100 measurements with a bit rate of 12.5 Mbps.

Description	Qty	w/ 30% Growth	Bit Resolution	Sample Rate (per second)	Bit Rate (bps)	Bit Rate w/ 30% Growth (bps)
Strain Guage	200	260	8	50	80,000	104,000
Static Pressure	268	348	8	50	107,200	139,200
Air Data (Rakes)	240	312	12	50	144,000	187,200
Air Data (FADS)	13	17	12	50	7,800	10,200
Unsteady Pressure	476	619	12	1200	6,854,400	8,913,600
Microphones	16	21	12	6000	1,152,000	1,512,000
Vibration/Acceleration	58	75	12	1200	835,200	1,080,000
Thermal	52	68	8	50	20,800	27,200
Inertial	30	39	12	1200	432,000	561,600
Discrete	200	260	1	10	2,000	2,600
DFI Health Monitoring	60	78	8	10	4,800	6,240
Totals	1613	2097			9,640,200	12,543,840

Table 1. Preliminary Measurement List, Feb. 2006

In August 2006, the avionics contract (including implementation of the DFI) was awarded, and a team consisting of individuals from NASA was identified to lead the creation of the formal DFI list. Shortly after formation of the team, a request was made to the Ares Projects technical disciplines (aerosciences, thermal, structures, etc.) and the Ares I vehicle element offices to provide their specific input to the measurement list. When all of the inputs were consolidated, the list was more than an order of magnitude higher than the bit rate allocation in the avionics contract. This discrepancy necessitated a technical interchange meeting (TIM) with the measurement requestors. The purpose of the TIM was to reduce the DFI bit rate to the 12 Mbps limitation. Specific steps that were included in this effort were to eliminate sensor overlap between disciplines and elements; map each requested sensor to a specific flight test objective (or eliminate the sensor); and set up time-sequence formats for specific events such as ascent, separation, and FS descent. The TIM resulted in a reduction in the number of measurements to 1,673 with a corresponding bit rate of 10.3 Mbps.

The details of this list were delivered to the avionics contractor in December 2006; however, when a cost assessment was performed for procuring and implementing the list, it was determined that the measurement set did not fit into the budget allocation for DFI in the avionics contract. At this point, the Ares disciplines and elements were once again tasked to review the list for further reductions. In March 2007, a version of the measurement list that met the expected cost constraints was approved. This list consisted of 989 measurements with a bit rate of 9.0 Mbps and an additional 4.8 Mbps for ten high-frequency pyro-shock sensors to characterize the separation event following FS burnout.

Since March 2007, the measurement list has been relatively stable, undergoing a series of minor changes to get to the current list.[5] Among the changes were a reduction in the number of pyro-shock sensors when the separation event was changed from the Ares I scenario (FS separation at the top of the interstage, followed by separation of the interstage and frustum) to the one described earlier; updated positions of sensors due to interference with vehicle joints or structure; and specification of the phase of flight in which each measurement will be included into the telemetry stream. The current measurement list now consists of 901 measurements from 716 sensors with a total bit rate of 10.1 Mbps.

Details of on-board video imagery were first identified about the same time that the first measurement list was delivered to the avionics contractor. Initially, eight cameras were approved for implementation to provide video imagery during ascent, separation, and post-separation. When the decision was made to change to a different separation scheme than Ares I (see Reference 3), enabling the deletion of the three cameras that were to be used for video photogrammetry of the separation event, leaving five on-board cameras in the final DFI configuration.

Implementation of DFI

The DFI system for Ares I-X is basically a Commercial Off-The-Shelf design that is used extensively in aerospace testing. Figure 3 provides a schematic representation of the DFI system. All individual sensors are connected to one of five remote data acquisition units (DAUs). These remote DAUs are connected to three master DAUs that each create a separate pulse-code modulation (PCM) stream. The PCM streams are sent to one of two S-band transmitters for real-time telemetry. The PCM streams are also sent to a solid-state recorder located on the First Stage Avionics Module (FSAM), located in the FS fifth segment. The FSAM houses a significant portion of all of the avionics hardware boxes, including DFI. Video data from the on-board cameras are sent to both the on-board solid state recorder and combined into a single telemetry stream and digitally transmitted to the ground.

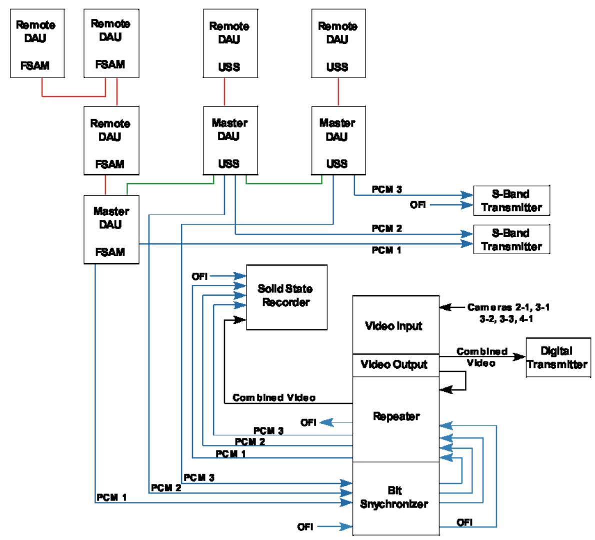

Figure 3. Top-level DFI system schematic drawing.

DFI Summary

Table 2 provides a summary of the number of Ares I-X DFI sensors both by technical discipline and by major part location on the vehicle. As can be seen, the thermal and aerosciences measurements each comprise about one-third of the total number. The aerosciences measurements will be used by the aerodynamics, aeroelasticity, and acoustics disciplines. About 20% of the measurements are dedicated to structures. Half of the DFI measurements are located on the FS, while the USS carries about 30% and the CM/LAS contains about 20% of the measurements.

Thermal					
Description	**Totals**	**CM/LAS**	**USS**	**IS**	**FS**
Calorimeter	97	8	12	15	62
Radiometer	6				6
Gas Temperature Probe	13		1		12
Static Pressure	62	4	11	8	39
Differential Pressure	9				9
Temperature	99	21	1		77
Thermal Totals	**286**	**33**	**25**	**23**	**205**
Structures					
Description	**Totals**	**CM/LAS**	**USS**	**IS**	**FS**
Internal Microphones	4	1	1		2
Accelerometer (LF)	42	15	16	11	
Accelerometer (HF)	8	5	3		
Biaxial Accelerometer (LF)	24				24
Triaxial Accelerometer (LF)	12				12
Triaxial Accelerometer (HF)	9		3		6
Strain Gauges	8		8		
Biaxial Strain Gauge	24				24
Triaxial Strain Gauge	54		12	36	6
Operational Pressure Transducer	2				2
Structures Totals	**187**	**21**	**43**	**47**	**76**
Pyro Shock					
Description	**Totals**	**CM/LAS**	**USS**	**IS**	**FS**
Forward Skirt Sep. Pyro Shock	2				2
Shock Totals	**2**	**0**	**0**	**0**	**2**
GN&C/Trajectory					
	Totals	**CM/LAS**	**USS**	**IS**	**FS**
Air Data Vanes	2	2			
5 Hole Probe (10 channels)	10	10			
Total Air Temperature Probe	2	2			
SIGI INU	20				20
BDM Case Strain	8				8
BTM Case Strain	4				4
GN&C/Trajectory Totals	**46**	**14**	**0**	**0**	**32**
Aerosciences					
Description	**Totals**	**CM/LAS**	**USS**	**IS**	**FS**
Unsteady Pressure (HF)	37	17	8	1	11
Unsteady Pressure (HF)	22	9	11	2	
Unsteady Pressure (LF)	239	66	65	16	92
Aero Totals	**298**	**92**	**84**	**19**	**103**
House Keeping					
Description	**Totals**	**CM/LAS**	**USS**	**IS**	**FS**
Lockheeed Accelerometer (HF)	13		6		7
Master DAU Status	39		26		13
Remote DAU Status	30		12		18
House Keeping Totals	**82**	**0**	**44**	**0**	**38**
DFI Totals	**901**	**160**	**196**	**89**	**456**
Notes: LF=Low Frequency, HF=High Frequency, INU=Inertial Navigation Unit					

Table 2. DFI Measurement Summary

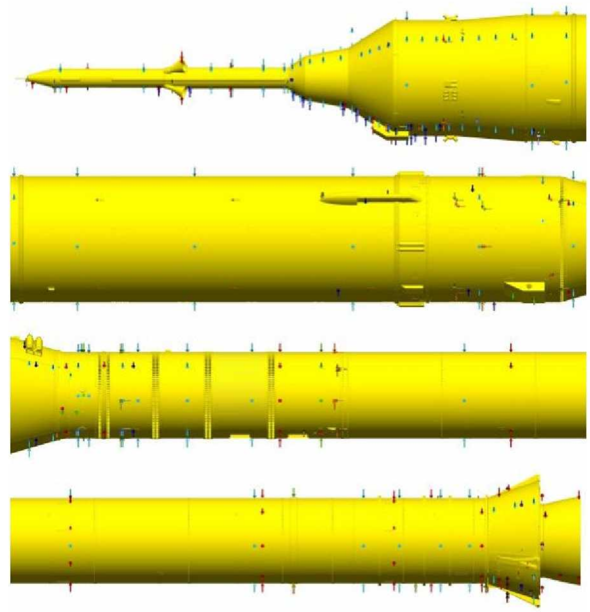

Figure 4. Ares I-X external DFI sensor layout.

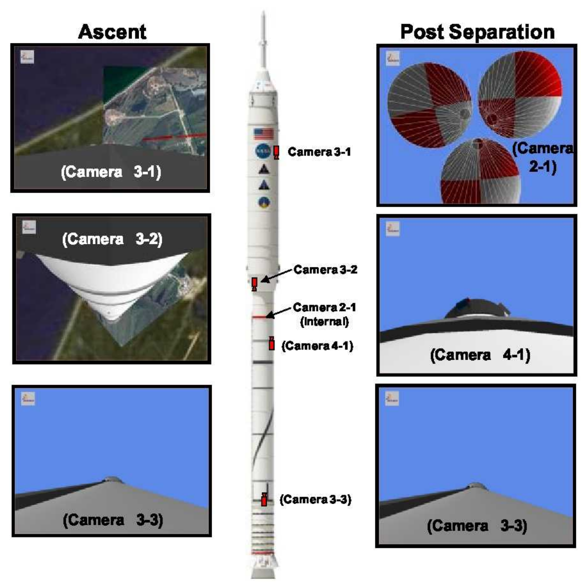

Figure 5. Ares I-X on-board video imagery.

Figure 4 provides images of the Ares I-X externally-mounted DFI sensor location layout. Sensor positions were chosen primarily to acquire a global characterization of the responses to induced environments or to determine specific details around protuberances or localized flow features (such as RoCS).

Summary details of the on-board imagery are shown in Figure 5. Ares I-X now contains five color video cameras to capture imagery during all flight phases of the mission. The imagery will be sent real-time in a single telemetry stream at a bit rate of about 14 Mbps (separate from the three DFI telemetry streams). The video will also be digitally recorded on board the vehicle.

Three cameras will be used to provide imagery data during ascent. Two of these cameras will be aft facing and are located on the USS and the frustum. The third camera is forward facing and located on the forward part of the FS aft motor segment. These cameras will detect debris shedding, evidence of RoCS firing, and will also provide imagery to be used by NASA public affairs. Following separation, two different cameras as well as the one on the aft motor segment will be used to provide imagery during FS tumble, descent, and set-up for recovery. One of the two cameras is located on the empty fifth motor segment simulator and will capture the deployment of the main parachutes from an external perspective; the other camera is located on the forward bulkhead of the forward skirt near the vehicle vertical axis and will provide a vehicle centerline view of parachute deployment.

DFI Criticality Definition

In order to address DFI sensor installation and checkout prioritization, the Ares I-X DFI Team developed criticality criteria for all sensors. The criteria were based on the Ares I-X flight test objectives (FTOs)[2]. There are five primary FTOs and six secondary FTOs as listed in Table 3.

Primary Flight Test Objectives	
P1	Demonstrate control of a vehicle dynamically similar to the Ares I/Orion vehicle using Ares I relevant flight control algorithms.
P2	Perform an in-flight separation/staging event between an Ares I-similar First Stage and a representative Upper Stage.
P3	Demonstrate assembly and recovery of a new Ares I-like First Stage element at KSC.
P4	Demonstrate First Stage separation sequencing, and quantify First Stage atmospheric entry dynamics, and parachute performance.
P5	Characterize magnitude of integrated vehicle roll torque throughout First Stage flight.
Secondary Flight Test Objectives	
S1	Quantify the effectiveness of the First Stage separation motors.
S2	Characterize induced environments and loads on the FTV during ascent flight phases.
S3	Demonstrate a procedure to determine the vehicle's pre-launch geodetic orientation vector for initialization of the flight control system.
S5	Characterize induced loads on the Flight Test Vehicle on the Launch Pad.
S6	Assess potential Ares I access locations in the VAB and on the Pad.
S7	Assess First Stage electrical umbilical performance.
	Note: S4 was deleted as a flight test objective.

Table 3. Ares I-X flight test objective.

FTOs P1, P2, P4, P5, S1, and S2 require data acquisition during flight to meet the stated objective. Some of the flight data will come from OFI, but the majority will be from DFI. In addition to these FTOs, a technical challenge that will impact the Orion/Ares I vehicle is first stage thrust oscillation. The mitigation approach for thrust oscillation will be enhanced by specific DFI that is included on Ares I-X to measure thrust oscillation magnitude during first stage flight.

The original three DFI criticality levels were identified as mandatory, highly desired, and secondary. Mandatory measurements are those that are required to meet a primary FTO. The mandatory sensors have a redundant measurement to improve the likelihood that the important data will be acquired during flight. Furthermore, they will be functional on day of launch, checked for ambient readings on day of launch, and included as launch commit criteria. The mandatory DFI measurements are presented in Table 4. Highly-desired measurements are those that significantly add to the benefit of the Ares I-X test flight relative to the primary FTOs. These measurements will be functional at the time of rollout, checked for ambient readings on day of launch, but not included as launch commit criteria. Finally, secondary measurements, as the name implies, are those that support secondary FTOs and/or supplement the primary FTOs. These measurements will be functional prior to stacking, not checked for ambient readings on day of launch, and not included as launch commit criteria.

Mandatory Measurement	Redundant Measurement	Objective
Total Pressure (5 Hole Probe)	Redundant Pressure Transducer	P1
Static Pressure (5 Hole Probe)	Redundant Pressure Transducer	P1
Plenum Pressure (5 Hole Probe)	Redundant Pressure Transducer	P1
Angle of Attack (5 Hole Probe)	Air Data Vane	P1
Angle of Sideslip (5 Hole Probe)	Air Data Vane	P1
Total Air Temperature Probe	Redundant Temperature Transducer	P1
First Stage Inertial Navigation Unit	Potential Radar Measurements	P2, P4
Operational Pressure Transducer (OPT)	Redundant OPT	Thrust Oscillations
Two Triaxial Strain Gage on Motor Dome	2 of 2 must be working	Thrust Oscillations
Four Strain Gages located at X_{FTV} = 2953	Two Strain Gages located at X_{FTV} = 2118	Thrust Oscillations
Four Accelerometers located in the axial orientation at X_{FTV} = 2953	Four Accelerometers located in the axial orientation at X_{FTV} = 2004	Thrust Oscillations
13 parameters from each of the three master DAUs for DFI System Health Status	N/A	DFI Hardware needed to meet P1, P2, and P4
6 parameters from each of the five remote DAUs for DFI System Health Status	N/A	DFI Hardware needed to meet P1, P2, and P4

Table 4. Mandatory DFI measurements.

Oversight of DFI Activities

In December 2008, the Ares I-X mission established the Ares I-X DFI Control Board (DXCB) to address and dispose of issues related to DFI. This allowed the Ares I-X Control Board to focus on flight preparations for the Ares I-X vehicle. The DXCB is also used to resolve installation and checkout issues associated with sensors and harnesses, as well as disposition discrepancies associated with DFI. Finally, an appeal process is in place to allow for reclama of decisions made by the DXCB.

Generation of "Silver Bullet" Sensor List

During the Ares I-X Critical Design Review in July 2008, one review board member raised an issue related to DFI. The issue was to develop and document an instrumentation verification plan for the DFI that demonstrates that the instrumentation, as installed, is performing adequately to provide engineering data of sufficient quality and accuracy to satisfy engineering requirements. While this request was not directly addressed by the Ares I-X MMO due to severe schedule and budget constraints, they asked that the engineering community identify a subset of current non-mandatory DFI sensors that, if raise to a higher status, would help answer some of the technical questions that have been raised by ground-based testing and analysis (e.g., wind tunnel tests and computational fluid dynamics analysis). During discussions with individuals in the Constellation Program Office, who understand both the need for sufficient flight data and the cost and schedule constraints of the Ares I-X mission, the suggestion was given that we "use our DFI 'silver bullets' wisely on the sensors that really matter." Thus, these sensors would be come to be known as silver bullet sensors.

The engineering team that was assembled to reclassify sensors was led by the Technical Fellow for Aerosciences at the NASA Engineering and Safety Center and included engineers representing the Ares and Orion Projects, as well as the Constellation Program. Many of these individuals were the original requestors of the sensors. The purpose of the team was two-fold. First, identify those sensors that should be considered on the silver bullet list due to the technical issues that they will address, as well as the locations on the vehicle considered important to obtain flight data. Second, determine the appropriate calibration and/or confidence checks that need to be performed on these sensors.

Four technical issues were determined by the team to be important enough to raise the importance level of existing sensors. These issues were fluctuating pressure environments (including buffet, aeroelasticity, and aeroacoustics), liftoff acoustics, thermal effects on the aft skirt and near RoCS plume interactions, and static pressure distributions in regions of high geometric change (such as the frustum/FS forward skirt area and the FS aft skirt). The CM/LAS also has significant geometric change, but because the CM/LAS for Ares I is now significantly different than for Ares I-X[3], the data obtained on that part of the vehicle will primarily be used for model validation.

Along with these technical issues, a prioritized list of five vehicle regions was deemed by the team to be important enough to raise the priority of sensors that were previously labeled as secondary. The highest priority region is near the RoCS to address unsteady pressure and thermal environments. Next, the FS frustum/forward skirt region is the focus of unsteady pressure measurements because wind-tunnel data of this type were significantly different from computational and analytical predictions, as well as to determine extent of RoCS plume impingement on the vehicle. Third, the FS aft skirt region (internal and external) is important for the prediction of static pressures, liftoff acoustics, and thermal environments (for both ascent and descent which could have implications on design of the aft skirt assembly). Fourth, the top of the Ares I upper stage houses the Instrumentation Unit, which contains a significant portion of the avionics hardware for the launch vehicle. Understanding the liftoff acoustics and aeroacoustics in this region will affect vibro-acoustic estimates for this region and could affect qualification of the Ares I avionics hardware or cause isolation mechanisms to be designed for them. Finally, the crew module/service module interface, while different on Ares I-X than Ares I, is a region where fluctuating pressure environments with the greatest prediction uncertainty on the vehicle are located. This is another region where wind-tunnel data were significantly different from pre-flight computational and analytical predictions.

Taking into account the recommendation of this team, as well as the redefinition of the highly-desired sensors to silver bullet sensors, Table 5 presents the types of sensors and regions in which they are located for the sensors that constitute the silver bullet sensor list.

DFI Measurement Type	RoCS/ Interstage	USS	Frustum/Fwd Skirt	5th Motor Segment	Instrum. Unit	Aft Skirt/ Nozzle	Aft Motor Segment	CM/LAS	CM-SM Interface	Totals
Calorimeter	5				1	18				24
Temperature	14				1	41				56
Static Pressure	5				1	12				18
Radiometer						5				5
Gas Temperature Probe						8				8
Differential Pressure						4				4
Pyro Shock Accelerometer			2							2
BDM/BTM Case Strain						12				12
Triaxial Strain Gauge	4									4
Triaxial Accelerometer (HF)					3					3
Triaxial Accelerometer (LF)	4	4	12							20
Accelerometer (HF)					1					1
Accelerometer (LF)								1		1
Unsteady Pressure (HF)	1		4		4	3			10	22
Unsteady Pressure (LF)	6		21	7	17	12		8	20	91
Video Camera		1	2	1			1			5
Subtotal	39	5	41	8	28	115	1	9	30	**276**

Table 5. Silver bullet sensor summary.

Status of Installation and Checkout

Prior to shipping sensors for installation, all DFI sensors received inspection and dimensional verification per specification data sheets, serial number identification, and a certificate of compliance. Where appropriate, calibration data sheets were provided for those sensors that received a specific factory calibration, and initial acceptance tests were performed for workmanship screening.

Installation of the Ares I-X DFI sensors was performed in various locations depending on the vehicle part. Most of the CM/LAS sensors were installed at NASA Langley Research Center in Virginia, USS sensors were primarily installed at NASA Glenn Research Center in Ohio, sensors on the four FS motor segments were installed by ATK in Utah, and most of the remaining sensors were installed at various locations in and around Kennedy Space Center in Florida, including Vehicle Assembly Building (VAB) High Bay 4 (where Ares I-X vehicle parts were located prior to stacking) and VAB High Bay 3 (where Ares I-X stacking was performed). All of the 901 measurements that make up the DFI list are expected to be installed on the vehicle.

Checkout of the DFI sensors was performed in four test configurations corresponding to different parts of the vehicle. Checkout consisted of two different activities. First, every DFI measurement was channelized. This was an end-to-end check from the sensor port to the DAU to ensure that the sensor measurement was located where it was supposed to be on the vehicle as well as on the data acquisition cards in the DAUs. The procedure included sensing a response when a stimulus was applied on the appropriate channel and that it responded in the correct direction. (For example, when heat was applied to a thermocouple, the counts output on the DAU increased.)

Second, following an assessment performed by all of the technical disciplines, the dynamic pressure sensors were determined to benefit from an additional confidence check that reduced the uncertainty of the measurements. Past history with these types of sensors, whose calibration curves were provided by the manufacturer's calibration, have shown that installation techniques, thermal cycles, and time could all contribute to higher uncertainty in their measurements.[6] No other sensor types were as susceptible to inaccurate measurements assuming that they were properly installed. Therefore, the decision was made to perform a confidence check on all silver bullet, dynamic pressure sensors. This was performed by providing a know pressure reduction (of about -5 psig), letting the measurement settle, check for leaks, record the pressure at the port, and record the counts output from the DAU. The process was then repeated at about -10 psig. Finally, the dynamic response of the sensor was checked by providing a known dynamic input and recording the output to determine whether that sensor responded as expected.

As of the August 17, 2009, 580 measurements were available for testing. Nine of those sensors remain to be tested. Of the 571 sensors that were tested, 548 sensors, or 96%, passed channelization. The remaining measurements will be tested in the next few weeks. **[Latest numbers to be included prior to final submission to the IAF.]**

POST-FLIGHT PLANS FOR DFI DATA USAGE

Aforementioned, Ares I-X has been defined such that the vehicle OML and other key features are an acceptable representation of Ares I. Ares I-X is instrumented with two purposes: (1) to allow assessment of primary and secondary FTOs and (2) to influence the Ares I design early in the design process. The Ares I-X MMO is responsible for post-flight assessment of FTOs and performance of the systems and components that comprise the Ares I-X vehicle. MMO is also responsible for providing data and certain analysis results for Ares I use. Planning for Ares I-X post-flight data analysis is documented in reference 7. The APO is responsible for using the Ares I-X development, flight, and post-flight analysis data to influence the Ares I design. Planning for Ares I use of Ares I-X data is documented in Reference 8. The integrated post-flight activities for MMO and APO are shown in Figure 6. Items to the left of the dashed line are the responsibility of MMO; areas to the right of the dashed line are the responsibility of APO. "Supporting Products" are provided by MMO and APO for use in model and process validation.

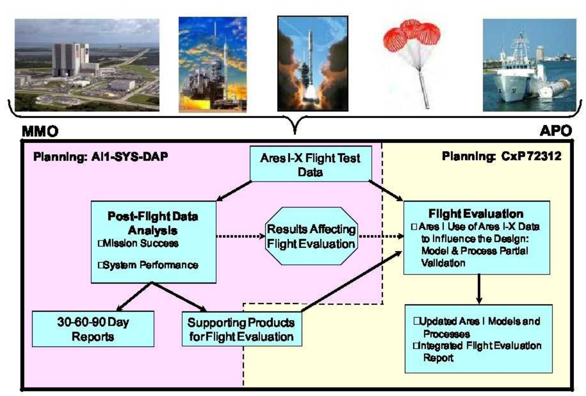

Figure 6. Ares I-X post-flight integrated activities.

Post-Flight Data Analysis Plan

The Ares I-X Flight Test Plan[2] requires assessments of both mission success and vehicle element and integrated system performance. A post-flight data analysis plan has been defined and developed in support of the Ares I-X MMO. The purpose of the Post Flight Data Analysis Plan is to define the processes for gathering, archiving and distributing the Ares I-X post flight data, validating primary and secondary FTOs, developing products in support of the Ares I design, and assessing the performance of the various Ares I-X systems.

Ares I-X Integrated Product Teams (IPTs) and SE&I will assess accomplishment of the FTOs as well as performance of the Ares I-X integrated vehicle and each of the IPT products. Results of the post-flight data analyses will be documented in reports issued by the MMO at 30, 60, and 90 calendar days after the Ares I-X launch. The schedule for post-flight data analysis is shown in Figure 7.

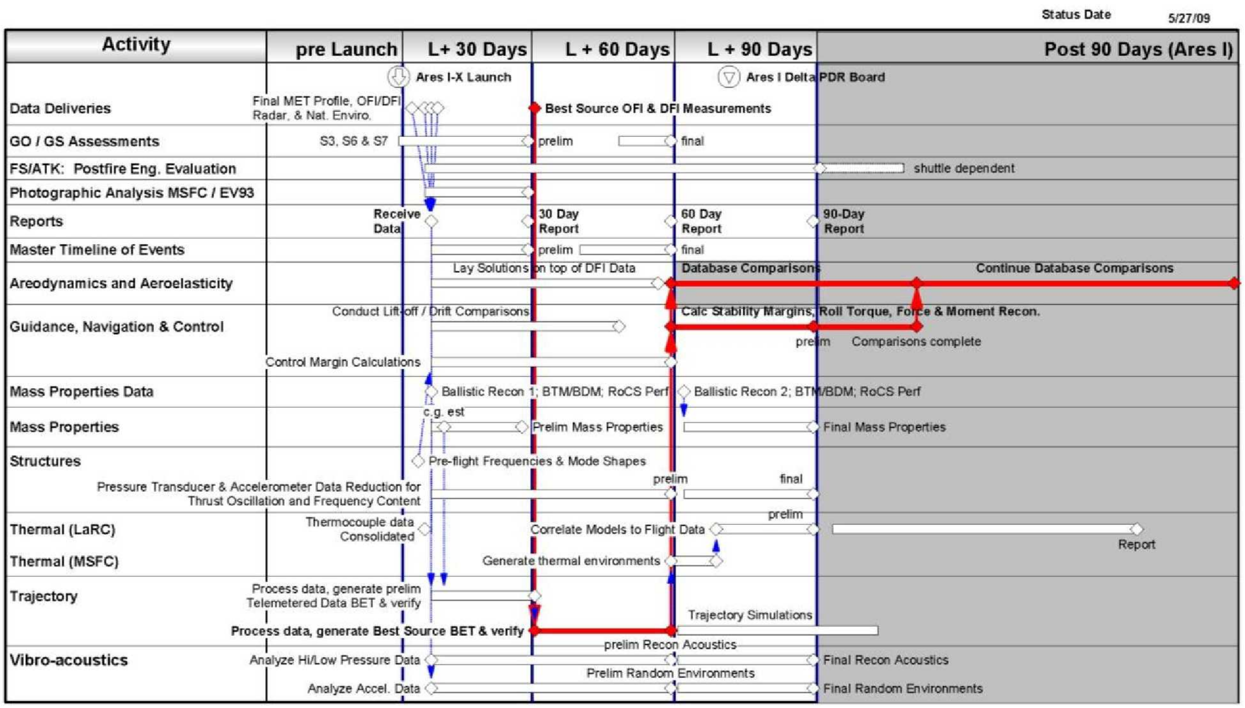

Figure 7. Post-flight data analysis master schedule.

Flight Evaluation Plan

The Ares I-X test flight offers a unique opportunity for early engineering data to support the design of the Ares I crew launch vehicle. A flight evaluation plan has been defined in support of the APO. This plan is known as the Flight Evaluation Plan for Ares I Use of Ares I-X Flight Data. The purpose of this document is to define the Ares I plan to utilize the Ares I-X flight data to influence the Ares I design. The Ares I design will be shaped by partially validating models and ground test data used in design of the Ares I flight vehicle as well as by assessment of Ares I-X vehicle characteristics of interest to Ares I. This plan defines engineering flight evaluation tasks to be implemented in order to validate design tools and to validate scaling used to translate ground test data for flight vehicle design application. It also defines plans for management of the flight evaluation effort and for documentation of results from engineering flight evaluation tasks. Ground operations are not addressed in this plan beyond their influence on the evaluation of the flight vehicle.

In order to organize the flight evaluation effort, flight evaluation tasks were defined for design disciplines that could benefit from the Ares I-X flight. Flight evaluation tasks were primarily organized along discipline lines (aerosciences; vehicle dynamics; guidance, navigation, and control; acoustic environments; etc.). In each of the disciplines, flight evaluation tasks assigned owners responsible for definition and execution of the individual tasks. Individual task owners defined flight evaluation tasks using a standard content template with the following attributes:

- Task Title
- Task Identification (ID)
- Task Owner
- Task Content

- Task Product
- Schedule for Task Product
- Supporting Products Required for Task
- Flight Measurements Required for Task

Table 6 lists the 33 tasks defined in the flight evaluation plan.

Task #	Task Title	Task ID
1	High-Altitude Deceleration (HAD) Model Validation	FSS001
2	First Stage Thermal Model Validation for Ascent and Re-Entry Heating	FSS002
3	Validation of First Stage Aft Skirt Vibration Environments Models	FSS003
4	Application of Ares I-X Thrust Oscillation Forcing Function to Ares I	FSS004
5	Evaluation of Motor Age on the Ares I-X First Stage Performance	FSS005
6	Validation of Thrust Oscillation Modeling	FSS006
7	Updated Ares I Rollout Loads Using Ares I-X Derived Base Acceleration	IVSL001
8	Updated Ares I Ground Wind Loads Using Ares I-X Ground Measurement System (GMS) Data	IVSL002
9	Updated Ares I Liftoff Loads Using Ares I-X Flight Data	IVSL003
10	Perform Loads Reconstruction for Ares I-X	IVSL004
11	Updated Ares I Separation Loads Using Ares I-X Flight Data	IVSL005
12	Validation of Vibroacoustic Prediction Methodology and Empirical Scaling Techniques	SLD001
13	Validation of Separation Pyroshock Attenuation Models	SHOCK001
14	Aerodynamic Database Generation Process Validation	AD001
15	Aeroelastic Fluctuating Pressure Model Validation	AD002
16	Validation of Ascent Aerodynamic Heating Code for Protuberances	AT001
17	Validation of First Stage Reentry Aerodynamic Heating Code	AT002
18	SRM Plume Radiation Code Validation	AT003
19	Validation of Semi-Empirical and Computational Fluid Dynamics (CFD)-Based Solutions for First Stage Plume Convection	AT004
20	Validation of CFD Code for First Stage Plume Induced Flow Separation	AT005
21	Validation of CFD Code for Small Motor/Engine Plume Impingement	AT006
22	Validation of FS RSRM Shutdown Spike Curve Fit Built into Current Models	AT007
23	Validation of Ares I Liftoff Acoustic Environments	AA001
24	Validation of Ares I Ascent Acoustic Environments	AA002
25	Validation of Ares I Venting Analysis Tools	VENT001
26	Gyrocompass Alignment for Launch	GNC001
27	Validation of Flight Control System Design Tools	GNC003
28	Validation of Trajectory Reconstruction Capability	TR-PER001
29	Validation of Best Estimate Trajectory (BET) Generation Capability	TR-PER002
30	Validation of SRB Performance Knock-Down	TR-PER003
31	Validation of First Stage/Upper Stage Separation Dynamics Modeling	TR-PER004
32	Validation of Vehicle Drift Modeling	TR-PER005
33	Evaluation of Abort Triggers Using Ares I-X Flight Data	TR-PER006

Table 6. Ares I-X Flight Evaluation Tasks

Figure 6 shows "Supporting Products for Flight Evaluation" that are supplied by both MMO and APO for use in the flight evaluation tasks. Supporting products are a combination of analysis results and other data required as input to a flight evaluation task. Examples of supporting products include preflight prediction data for comparison with measured flight data, as-built instrument locations, and a best estimated trajectory from flight. The Constellation Program computer application Constellation Analysis Integration Tool (CAIT) was used to formally document the supporting product exchange between MMO and APO. CAIT allows detailed definition of product content and provides a mechanism to document agreements on product delivery details.

A flight evaluation schedule template, Table 7, was supplied to the task owners. The template contained both suggested activities and flight evaluation milestones. Each task owner was asked to customize the schedule while maintaining the flight evaluation milestones. The customized schedules are documented in Reference 8.

Time	Description
L - 2 weeks	Analytical Predictions for Comparison Completed and Documented
L + 4 days	Preliminary Flight Data Available for Comparison
L + 35 days	Best Source Flight Data Available for Comparison
L + 36 days	**Flight Evaluation Kickoff Meeting**
L + 8 weeks	Initial Comparisons of Predicted and Actual Data Presented to Appropriate Panel/Team
L + 12 weeks	Final Comparisons of Predicted and Actual Data Presented to Panel/Team - Data Comparisons - Model and Process Updates Assessment
L + 20 weeks	Panel/Team Review of Final Task Product Completed
L + 22 weeks	Technical Management Team Vetting of Final Task Product Completed
L + 24 weeks	Updates to Model and/or Process Implemented for use in Ares I Critical Design Review Analyses
L + 26 weeks	**Task Product Transmitted to Flight Evaluation for Integration into the Final Flight Report**
L + 28 weeks	**Final Flight Evaluation Review Presentation**
L + 30 weeks	**Integrated Flight Evaluation Report Delivered**
	Notes: **Bold Font = Flight Evaluation Milestone** L = Launch

Table 7. Ares I-X Generic Flight Evaluation Template

In short, the Ares I-X post-flight data analysis and flight evaluation plans are in place, are prepared to support an assessment of flight success against the FTOs, and provide valuable data in support of the Ares I design and development prior to the Ares I Critical Design Review.

SUMMARY

The Ares I-X flight test vehicle is an unscrewed, ascent development flight test that will acquire flight data early enough to impact the design and development of the Ares I. As the primary customer for flight data from the Ares I-X mission, Ares I was the major driver in the definition of the Development Flight Instrumentation (DFI). This paper presented a perspective in the development and implementation of the DFI, including the process by which the list was established and changes were made to that list due to imposed constraints.

There are two lessons that were learned during this process. First, understand and have agreement from all appropriate organizations defining requirements and flight test objectives. This step will dictate the basis for debating the merits of each sensor. Second, do not start at infinity and work down to the final number of sensors. Put another way, those who have inputs to the DFI sensor count should expect this to be a list based on needs, not desires. A tremendous amount of time and effort was expended in the numerous DFI reductions. DFI reductions have proved to be disruptive late in the vehicle preparation process. It is suggested that DFI allocation discussions for future vehicles include providing a fixed part of the bandwidth capability to technical disciplines and elements and have them work to stay within that allocation.

The paper also discussed the plans for the analysis of the DFI data following the flight and a summary of flight evaluation tasks to be performed in support of tools and models validation for design and development. The initial data analysis will be used to assess mission success and integrated vehicle performance. The flight evaluation that follows will provide Ares I engineers flight data from a relevant vehicle that will be used to validate (and possibly update) tools and models being used to design Ares I. These data will be provided in sufficient time to be included in their Critical Design Review, currently scheduled for Spring 2011.

ACKNOWLEDGEMENTS

This paper provided a very high-level summary of the work performed by an extremely dedicated number of individuals across the Ares I-X Mission Team who have supported the DFI cause and the benefits that the Constellation Program will reap from the data that will be acquired from this flight. The following individuals deserve specific recognition: Daniel Norfolk, Bradley Crawford, James Fay, Keith Harris, and Van Woodruff.

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ACRONYMS

APO	Ares Projects Office
BDM	Booster Deceleration Motor
BTM	Booster Tumble Motor
CAIT	Constellation Analysis Integration Tool
CM/LAS	Crew Module/Launch Abort System
DAU	Data Acquisition Unit
DFI	Development Flight Instrumentation
DXCB	Ares I-X DFI Control Board
FADS	Flush Air Data System
FS	First Stage
FSAM	First Stage Avionics Module
FTO	Flight Test Objective
HF	High Frequency
INU	Inertial Navigation Unit
IPT	Integrated Product Team
KSC	NASA Kennedy Space Center
LF	Low Frequency
MMO	Mission Management Office
OFI	Operational Flight Instrumentation
OML	Outer Mold Line
OPT	Operational Pressure Transducer
NASA	National Aeronautics and Space Administration
PCM	Pulse Code Modulation
RoCS	Roll Control System
RSRM	Reusable Solid Rocket Motor
SIGI	Space Integrated GPS/INS
USS	Upper Stage Simulator
TIM	Technical Interchange Meeting
VAB	Vehicle Assembly Building
X_{FTV}	Axial station in Ares I-X coordinates (in inches)